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ADMINISTRATION

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PROVISIONAL SPECIFICATION

Applicant(s):

COMMONWEALTH SCIENTIFIC AND INDUSTRIAL RESEARCH ORGANISATION

Invention Title:

A SYSTEM FOR MONITORING ACOUSTIC EMISSIONS FROM A MOVING MACHINE

The invention is described in the following statement:

A SYSTEM FOR MONITORING ACOUSTIC EMISSIONS FROM A MOVING MACHINE

Field of the Invention

This invention relates to the monitoring and analysis of surface vibration waves generated by the operation of material processing equipment. 'The invention is of particular application to the non-intrusive monitoring and control of mineral processing equipment, such as tumbling mills, where the equipment component being monitored is in motion. The invention also has application to equipment with stationary components but moving mineral particles or pulp flows, such as crushers and hydrocyclones. The invention was initially developed for condition monitoring and process control of Semi-Autogenous Grinding (SAG) mills.

Background of the Invention

Acoustic emissions and surface vibrations monitoring have previously been used to investigate and control the performance of mineral processing unit operations. Control of power draft in autogenous grinding (AG) mills and SAG mills has traditionally been via load cells estimating the charge mass. However, acoustic emissions from dual microphone systems have been used to monitor the changing level of impact of the charge on an AG mill shell. A pair of microphones were mounted at approximately 30° from the bottom and 30° from the centre line of the mill. The position of the microphones was such that the upper unit was above the normal level of charge impact on the liner while the lower unit was below the same. If the load level rises in the mill, the point of impact moves toward the upper microphone and away from the lower. If the load level drops, the converse applies. Therefore changes in load level are registered by variation in the comparative sound intensity at the two microphones. The resulting estimate of the load volume is correlated with the power draft and used to control the feed rate in order to maintain optimal milling conditions and maximum

power draft. It was shown that microphone signals are much more sensitive to load change than the load cell. However, the method is crude in that it uses sound intensity at only two fixed points outside the mill. The intensity of sound at these two positions may be considerably influenced by events both outside the mill and at a variety of locations within the mill. The technique therefore only permits qualitative investigation of the state of the charge inside the mill.

Acoustic emissions are also known to be indicators of pulp density and viscosity. The dual microphone study of AG mill acoustic emissions showed that the sound intensity emanating from the charge region (lower microphone) was correlated with the pulp density. The lower microphone sound intensity was used to control water addition rate. Low pulp density was thought to result in higher transmission of noise and increased media/media and media/liner collision events. Meanwhile at higher pulp density grinding action was thought to be inhibited by the increased pulp viscosity, reflected in lower noise intensity. Estimation of effective pulp density and viscosity via the magnitude of acoustic emissions has also been achieved for laboratory batch ball mills. Results suggest that changes in mill noise can be used to identify the pulp rheological regime and potentially used to optimise grinding efficiency. Mill sound noise has also been shown to indicate charge size distribution, ore breakage rates, and ore character in batch ball mills (Watson, 1985; Watson and Morrison, 1985).

Acoustic emissions monitoring has also been used to analyse hydrocyclone performance. A shear structure piezoelectric type acoustic sensor was mounted halfway along the conical section of a 5" hydrocyclone body. The digitised signal was sampled at 2000 Hz and a Fast Fourier Transform (FFT) algorithm used to derive the Power Spectral Density function (PSD) for analysis of acoustic emission characteristics in the frequency domain. Features of

acoustic emissions were analysed for varying feed solids concentrations and pressure. Results indicated significant spectral features in the frequency range from DC to about 50 Hz and between 30 and 45 Hz. The height of these

5 spectral features was sensitive to operating conditions. It was conjectured that the spectral structure is related to features of the hydrodynamics inside the hydrocyclone local to the sensor. A stepwise regression analysis technique was used to derive linear relationships between the operating

10 parameters of the cyclone and the spectral and statistical characteristics of the acoustic emissions. The signal measures used in this analysis were for the time domain maxima, mean, standard deviation, rootmean-square, skewness and kurtosis, and for the frequency domain the first 52

15 spectral components of the PSI). The model was then used for reasonable predictions of hydrocyclone feed pressure, solids concentration, mass and volume flow rates and underflow concentration. This investigation showed that non-invasive acoustic emission measurement coupled with

20 multivariate statistical analysis techniques are a useful tool for monitoring the bulk characteristics of both process and equipment, in this case hydrocyclone operation.

Vibration monitoring and signal analysis have been used to study the feed distribution characteristics of

25 parallel Dense Medium (DM) cyclones in a coal preparation plant. The method is based on the concept that the monitoring of vibrations on the external surface of the cyclone can yield the frequency and strength of particle impacts (particularly for larger particles near entry and

30 exit points). Accelerometers for measuring vibrational accelerations were mounted near the feed inlet, underflow spigot and overflow cap. Relatively large vibrations were noted in the region of the overflow cap, reflecting the energy of particle/wall impacts in that region due to the

35 flow regime within the cyclone. Results indicated that vibration measurements are a superposition of a large number of transients caused by individual particle impacts.

Summary of the Invention

According to the present invention a system is provided which is capable of monitoring acoustic emissions from a moving machine.

5   The invention includes within its scope systems for monitoring moving substances within a stationery or moving machine.

The system in broad terms is directed at monitoring mechanical wave emissions from inside the

10   machine and the surface of the machine, as well as associated components of the machine which are affected by the machine's operation.

Summary of the Invention

According to a first aspect, the invention

15   provides a system for monitoring acoustic emissions from a machine which in operation has moving particulate matter therein, the system including at least one sensor located on the machine at a location away from the central axis of the machine, the second being for sensing acoustic waves

20   and including a transmitter for transmitting signals representing the sensed acoustic waves to a receiver at a location remote from the sensor(s); a data processor connected to the receiver for receiving signals from the receiver which signals represent the acoustic waves and

25   processing the signals to produce output signals for display on a display means, wherein the output signals for display represent one or more parameters indicative of acoustic waves emitted from the machine over a predetermined period of time.

30   It is preferred that the output signals represent a number of acoustic events occurring within the machine, amplitudes of the acoustic events and data relating to the position of the acoustic events.

It is preferred that the system includes a

35   plurality of sensors each for detecting acoustic emissions from inside the machine and from the surface of the machine.

It is preferred that the system includes a plurality of sensors spaced around the periphery of the machine to enable polar co-ordinates of the origin of emissions to be located.

5   It is preferred that the sensors are equispaced around the periphery of the machine.

According to one embodiment of the invention sensors are arranged in an array around the machine and along the length of the machine to enable a three-

10   dimensional co-ordinate axis to be plotted of the location of the origin of emissions from the machine.

It is preferred that these sensors are removably attached to the outer surface of the machine.

According to one embodiment the transmitter

15   associated with each sensor is located away from a detector part of the sensor.

According to one embodiment one or more transmitters of the sensors are removably attachable to the machine.

20   It is preferred that the system includes at least one proximity detector for monitoring the location of the sensors at a predetermined time.

According to one variation of the present invention the data processor includes a timing means for

25   calculating the location of the sensor(s) at a predetermined time.

It is preferred that the timing means output data relating to the position of the sensor(s) at a particular time, based on data received either from the proximity

30   detector(s) or/and data received relating to the movement of the machine.

It is preferred that the data processor receives signals from the receiver, which signals include data relating to the frequency of vibrational events occurring

35   within the machine and the amplitude of the vibrational events at particular locations within the machine.

It is preferred that the sensor(s) includes an

accelerometer.

It is preferred that the sensor includes a power supply.

The power supply may be a solar cell.

According to another aspect of the present invention there is provided a method of analysing operational parameters of a machine having a moving particulate material therein, the method including the steps of recording data representing a number of vibrational events occurring within the machine over a predetermined period of time, the amplitude of the vibrational events occurring over the predetermined period of time and positional data relating to the position of the vibrational events occurring within the machine, displaying a graphical representation of the recorded data, the graphical representation including parameters relating to the number of vibrational events, the amplitude of vibrational events and the position of vibrational events occurring within the machine during the machines operation.

It is preferred that the graphical representation includes data on the radial and angular position of each vibrational event.

Preferably the graphical representation shows the number of vibrational events on a polar co-ordinate graph.

According to one embodiment the step of displaying includes displaying a histogram of variables relating to the number of vibrational events occurring over the predetermined time.

The present invention also includes within its scope graphical representation of the recorded data in a rectilinear co-ordinate system and three dimensional co-ordinate system.

According to one embodiment of the present invention the step of displaying includes displaying a graphical representation of the recorded data on a data processing monitor using 3D graphics which simulate the machine and provide a graphical representation of the

moving particulate material within the machine.

It is preferred that the step of displaying includes highlighting regions within the machine which have vibrational events liable to cause maximum damage to a
5   component of the machine.

According to another variation of the present invention the graphical representation includes a colour scheme for colouring regions of the graphical representation according to features of vibrational events
10   occurring at positions of the vibrational events.

According to another aspect of the present invention there is provided a method of controlling operational parameters of a machine having a moveable substance therein, the method including the steps of
15   recording data representing a number of vibrational events occurring within a machine over a predetermined period of time, amplitude of the vibrational events occurring over the predetermined period of time and position data relating to the position of the vibrational events over the
20   predetermined period of time, determining zones within the machine which are subject to predetermined levels of wear and altering the machine operational characteristics to reduce the levels of wear for the zones.

It is preferred that the step of determining
25   zones, includes processing the recorded data with data relating to the substance or substances within the machine, and dynamic properties of the substance(s) to produce a level of wear indication parameter for a plurality of zones within the machine.

30   It is preferred that the method includes operating a data processor which includes recorded model data relating to wear characteristics of the machine as a function of a plurality of parameters which may include one or more combinations of the following:

35   The number of vibrational events occurring within the machine, the amplitude of the vibrational events occurring within the machine, the position of the

vibrational events occurring within the machine, the mass of the particulate material and other material substance(s) within the machine, the size of the particulate matter within the machine, the volume of particulate matter within the machine, the volume of space within the machine, the shape of the machine and other parameters which are likely to affect the wear characteristics of the machine.

Alternatively the method of controlling the machine includes determining the efficiency of operation of the operational characteristics of the machine.

It is preferred that the method includes the step of processing the recorded data with other data relating to characteristics of the particulate matter and machine to determine the efficiency of operating characteristics of the machine.

The operating characteristics could include the efficiency of a crushing operation over a predetermined period of time.

It is preferred that the method includes the step of increasing or decreasing the speed of operation of the machine, including rotation or reciprocating motion of the machine and/or alteration of rate of feed of particulate matter to the inside of the machine.

It is preferred that the method includes the step of maximising a predetermined operational parameter of the machine. This may include maximising the amount of crushing of a material within a machine that is a crusher.

Brief Description of the Drawings

Preferred embodiments of the present invention will now be described by way of example with reference to the accompanying drawings in which:

Figure 1 shows a schematic of grinding media behaviour in a SAG Mill rotating at abnormally high speed;

Figure 2 shows a schematic of a basic system for monitoring acoustic emissions from a rotating machine;

Figure 3 shows a graphical representation of an accelerometer response on a rotating SAG Mill as a function

of time;

Figure 4 shows a polar contour plot of the natural logarithm of the number of vibrational events as a function of amplitude (volts) in the radial direction and mill rotation phase angle (degrees anti-clockwise) in the azimuthal direction with an SAG Mill rotating clockwise;

Figure 5 shows a graphical representation of power spectral density plot upto 1,000 Hz, the parameters are 2^{16} FFT length, 2^{15} number of samples overlap, FFT length Hanning windowing and nil detrending;

Figure 6 shows a graphical representation of power spectral density plot upto Nyquist frequency, the parameters are 2^{10}FFT length, 2^9 number of samples overlap, FFT length Hanning windowing and nil detrending;

Figure 7 shows a histogram of the natural logarithm of the total number of vibrational events occurring within an SAG Mill, as a function of event amplitude;

Figure 8 shows a graphical representation of a SAG Mill gross power as a function of the standard deviation of surfaces for three different mill speed settings; and

Figure 9 shows a graphical representation of pulp density (percent solids) as a function of the standard deviation of surface vibrations for two different sets of mill conditions.

Preferred Embodiment of the Invention

An example of a system for monitoring vibrational events occurring within an SAG 10 Mill will now be described.

An SAG Mill 10 consists of a metal cylindrical drum containing ball bearings and particulate matter to be crushed.

The surface of the mill 10 is provided with an accelerometer 11 which is movably fixed thereto and includes a radio transmitter.

A solar panel 12 is electrically connected to the

accelerometer 11 to provide a power supply.

A radio receiver 13 is connected to a stationery part of the SAG Mill framework and receives data transmitted by the radio transmitter of the accelerometer 5 11.

The radio receiver is hardwired to a terminal block 14 and a laptop computer 15 is able to be connected to the terminal block to receive data sensed by the accelerometer.

10 One or more proximity switches are located on the rotating part of the mill 10 to enable the position of the accelerometer to be located relative to the rate of rotation of the mill.

The operation of a SAG mill 10 results in the 15 generation of high frequency surface waves on the outside of the rotating shell due to collision events within the mill. Monitoring of surface waves with a sensitive accelerometer therefore provides information on events inside the mill, particularly impacts of grinding media on 20 the liner The grinding media is defined here as non-ore (often steel balls) and ore particles (the larger size fractions of which contribute to impact grinding). However, measurements of surface vibrations on the outside of the shell do not simply reflect local impact events on the 25 inside of the liner. All of the components of the mill behave to some extent as elastic media, permitting the propagation of waves generated by collision events within the mill, 'flexing' of the mill shell during rotation and external sources such as the drive motor and girth gear. 30 Transverse surface vibrational waves propagate around the inside of the liner and-around the outside of the shell. Meanwhile longitudinal sound waves travel through the charge and between the liner and shell. An accelerometer mounted on. the outside of the shell registers normal 35 acceleration due to waves transversely propagating around the shell. These waves are damped in accordance with the properties of the elastic media between the point of wave

registration and the origin of the causative event. Hence vibrational events as measured by an accelerometer can be expected to be due to causative events over a limited range of locations within the mill and associated assembly.

5 However, for preliminary analysis it is assumed that the vibrations are locally, generated by collision events inside the mill, adjacent to the accelerometer.

The behaviour of grinding media in a rotating SAG mill 10 is usually characterised in a similar manner to

10 balls in a ball mill. Grinding regions are expected to consist of the following (see Fig. I):

- shearing layers of media near the base of the charge article shatter and cleavage (region 1).
- tumbling media from high to low gravitational

15 potential near the top of the charge causing particle shatter (region 2).
- cataracting media impacting in the 'toe' region of the. charge causing particle shatter (region 3).
- some abrasion breakage between the grinding

20 media and the 1 liner (region 4).

Higher mill rotational speeds cause cataracting grinding media to directly impact on the liner above the 'toe' of the charge (Fig. 1, section 5). Liner 'Wear is

25 approximately proportional to the square of the mill speed and increases with grinding media size due to the consequent increase in impact energy. It is known that the presence of mineral slurry is very effective in damping the impact force of grinding

30 media on the liner. Hence liner cracking is interpreted as evidence of a problem of excessive direct impact of grinding media on the liner. The lifter profile also plays a strong role in determining the trajectory of cataracting grinding media and hence both the location and energy of

35 impact of the grinding media on the charge or the liner wall. A rectangular lifter profile is thought to result in the widest profile of cataracting events for a given mill

speed and charge volume This could be interpreted as meaning that a rectangular lifter profile leads to the highest inherent likelihood of large impact events directly on the liner. The composition of the liner itself directly

5   influences both impact and abrasion resistance. Use of a liner material that is strongly resistant to abrasion often results in low impact resistance and hence an increased propensity to cracking. Other causes of liner wear are corrosion (in wet mills) and abrasion. However, these sorts

10   of wear are not expected to be manifested as liner cracking. A non-intrusive means of quantifying the spatial position and intensity of the various types of grinding behaviour in SAG mills would be very useful for process monitoring and control. SAG mill operators are very keen to

15   use a technique that provides a reliable measure of mill load Monitoring of the frequency and spatial position of large energy particle impacts would also be very useful for monitoring and controlling SAG mill liner wear.

Apparatus

20   The surface vibration monitoring system can be configured in two ways - basic or advanced. The following provides a description of each configuration.

Basic system

         The surface vibration monitoring apparatus

25   consists of a Bruel and Kjaer accelerometer type 4393 connected to a Bruel and Kjaer charge amplifier type 2634. The output from the charge amplifier is connected to a microphone beltpack transmitter (AKG type BT5 1) powered by a 12 volt gel-cell rechargeable battery. Battery recharging

30   is achieved using two solar panels mounted on opposite sides of the mill. Transmitted data is received using a microphone wireless receiver (AKG type SR5 1) with two modified extended antennae.

         Receiver output is connected to a terminal block

35   and ribbon cable. The ribbon cable is connected to fast data acquisition PCMCIA DAQCard-Al-1 16E -4 linked to a laptop computer.

A magnetic proximity pad was mounted on the mill ;at 3 o'clock looking from the discharge end. The detector/switch was mounted off the mill and connected to the terminal block mentioned above. The switching signal

5 from the proximity detector is used as a trigger for logging of the accelerometer signal.

The software (written in LabView) can be triggered manually or digitally. Triggering occurs when the magnetic pad and detector/switch comes in close proximity

10 as the mill rotates and a 5 volt signal changes to 0 volts. Data acquisition then begins with the data being read into a rolling buffer and stored into five data arrays. Acquisition rate is adjustable up to 100k samples/s. At the end of the acquisition process, the mean of the arrays is

15 calculated as well as the standard deviation. This; data is stored in a file retrieved using Excel and contains the following information:

• Time in seconds from when the system first began logging.

20 • Signal mean in volts.

• Signal standard deviation in volts

• Sample size.

Unprocessed raw data was also saved in binary format for further data processing analysis as mentioned

25 later.

Advanced system

The advanced system includes the basic system described above plus one or more additional accelerometers and associated equipment. The accelerometers are of the

30 same type as described above. The main difference with the advanced system is an improved radio transmission and reception apparatus to enable data acquisition down to lower frequency ranges (around 1 Hz). The apparatus consists of an Adam module digital radio modem and

35 reception system linked to an on-mill computer that performs preliminary signal processing before transmission to the logging computer. The improved system can run in

parallel beside the basic system and data is logged and saved on the same laptop. The advanced system requires extra power for operation so extra solar panels are required compared with the basic system. The advanced

5   system can consist of multiaccelerometers either in basic or advanced configuration to investigate low frequency events, event spatial localisation, and events occurring on the ends of the mill. Signal data processing techniques are then used to determine surface vibration features for given

10   operating conditions. A schematic of the basic system attached to the shell of a SAG mill is shown below.

EXPERIMENTAL DESIGN

Two series of surface vibrations monitoring runs were conducted on the SAG mill at the Red Dome gold mine,

15   using the basic system of apparatus. The first was a limited series of test runs at different mill operating conditions essentially to test the system and establish that under severe plant duty the system produced data that could be processed. Qualitative evaluation of the data

20   clearly indicate that features of the data (in the form of a voltage-time trace) changed at different operating conditions. Features identified were: the minimum signal strength, length of time between start of signal and proximity signal, length of time for events to return to

25   background, maximum signal size, number and position of high frequency/high energy spikes, amplitude of high energy spikes and variation between successive revolutions. These results highlighted the necessity for further surface vibrations monitoring of the Red Dome SAG mill using a

30   conditional experimental design so that the influence of only one variable could be measured in the context of changes in surface vibration features. Thus, this approach would better characterise the potential relationships between features and operating settings.

35   The second series of test runs at Red Dome conformed to the conditional experimental design approach. A total of 23 test runs were conducted to investigate how

surface vibration features changed with one manipulated operating variable at a time. The manipulated operating variables were tonnage rate, mill speed, mill discharge density and ball addition. In addition to acquiring surface

5   vibration information, both control system data and physical plant measurements were taken at each set of conditions to confirm test run validity.

Faster acquisition speeds were possible for the second series of tests and a range of data was collected at

10   each manipulated mill condition. A 'normal' run was conducted first at a scan rate of 5 x 10' scans/s with raw data and statistical averages of the mean and standard deviation being saved. Then a 'fast' run, with acquisition rate increased to 1 x 10' scans/s, was conducted for a

15   duration of 1 X 106 scans. Following the fast run, a run using the original LabView VI written for the first series of lest runs was conducted at the same speed as a 'normal' runs listed above and saved to a binary file. Lastly, a 'long' run was conducted with the acquisition speed set at

20   5 x 10' scans/s for a duration of 1 X 106 scans. Listed below are the range of conditions for the manipulated operating variables:

Manipulated variable - tonnage (range 170-200 tph)
- Mill speed - 11.8 rpm

25   - No ball addition
- Pulp density - 72% solids w/w.

Manipulated variable - speed (range 12.3-13.8 rpm)
- Tonnage - 2 10 tph
- No ball addition

30   - Pulp density - 72% solids w/w.

Manipulated variable - ball addition (no-yes 1 kibble)
- Tonnage - 2 10 tph
- Mill speed - 13.8 rpm
- Pulp density - 72% solids w/w.

35   Manipulated variable - pulp density (65-72% solids w/w)
- Tonnage - 210 tph
- Mill speed - 12.5 rpm

- No ball addition

Manipulated variable - pulp density (72-82% solids w/w)

- Tonnage - 210 tph
- Mill speed - 14.5 rpm
5   - No ball addition

A number of other tests were conducted at intermediate conditions for tonnage and speed within the range listed above.

DATA ANALYSIS TECHNIQUES

10   The goal of the data analysis techniques is to derive quantitative measures and qualitative visualisations based on the response of the accelerometer to shell vibrations that can be correlated with SAG mill operating conditions. This enables vibration measurements to be used 15 for process condition monitoring and as an input to unit control. The measures are also useful for inference of the rate of liner wear as a function of operating conditions in with the SAG mill.

Surface vibrational waves as registered by an 20 accelerometer are characterised by a wide variety of measures. The first step in data processing prior to deriving any of these measures is to truncate the data to an integral number of mill rotation periods. This is done in order to ensure that there is no bias in the data due to 25 the sensor detecting changes in mill conditions as a function of rotational position of the outer shell.

The concept of a shell surface vibration event is important in the data processing. Such an event is defined as a positive deviation from nil accelerometer response. 30 The amplitude is taken as the peak accelerometer response associated with a positive acceleration. This is in accordance with a propagating surface wave inducing a positive acceleration in an accelerometer corresponding to a normal stress outwards from the shell. It is hypothesised 35 that collision events within the mill, particularly grinding media/liner events, will induce a strain that will propagate as a wave to the outside of the shell and be

initially sensed as a positive acceleration. A wave train due to a collisional event should be composed of an initial relatively large, positive acceleration followed by negative and positive oscillations of rapidly decreasing
5 amplitude. It is expected that the accelerometer will detect only the first few oscillations of any wave train associated with a particular collisional event. Negative accelerations are interpreted as part of a wave train belonging to a previous positive acceleration and are hence
10 discarded in terms of registering distinct events. Subsequent positive oscillations in a wave train are expected to be highly damped due to the low elasticity and high damping properties of the liner and the outer shell. Hence it is reasonable that each sequence of positive
15 acceleration defines a vibrational event caused by a particular media/media or media/liner collision within the mill.

The various measures used to characterise surface vibrational waves are as follows:

20   1.   Mean and standard deviation of the sampled signal.

         2.   Power spectral density of the sampled signal.

         3.   Histograms of sampled signal amplitude.
25 This includes histograms of sampled signal, absolute value of sampled signal and the natural logarithm of the absolute value of the sampled signal.

         4.   Total number of signal samples and the ratio of large to small amplitude samples. The cut-off amplitude
30 between large- and small-scale accelerometer responses is user defined.

         5.   Mean and standard deviation of the amplitude of surface vibrational events.

         6.   Mean and standard deviation of the phase (in
35 terms of the position of the accelerometer in the rotation cycle of the mill) of surface vibrational events.

         7.   Mean and standard deviation of the phase (in

terms of the position of the accelerometer in the rotation cycle of the mill) weighted by amplitude of surface vibrational events.

8. Histograms of surface vibrational event magnitude. This includes histograms of amplitude and the natural logarithm of the amplitude of events

9. Total number of events and the ratio of large to small amplitude events. The cut-off amplitude between large- and small-scale accelerometer responses is again user defined.

10 Power spectral density of the sampled signal derived from the amplitude versus time accelerometer response.

11. The energy of the sampled signal as derived from the power spectral density, in the frequency bands 0-100 Hz, 100-300 Hz and 500-700 Hz. These frequency bands are deemed by experience to contain most of the surface vibrational wave energy information that varies with mill operating conditions.

12. The total energy of the sampled signal derived from both the power spectral density and the amplitude versus time accelerometer response.

13. Contour plot of vibrational event numbers as a function of SAG mill phase angle and event amplitude. Event amplitude and phase angle are identified as associated with the maximum positive excursion of the accelerometer response for any particular event. The natural logarithm of surface vibrational event numbers is plotted in order to emphasise the position angle of' relatively large amplitude but infrequent events.

All the above measures are derived for each revolution of a continuous monitoring period and over the entire integral number of mill revolutions of the same. The signal analysis software has been implemented in the MATLAB technical computing language. However, any and all of the components of the software could be implemented in -a variety of other programming languages.

A typical accelerometer response trace as a function of lime for a rotating SAG mill is shown below (Fig. 3). In this case four full mill revolutions of data (5 x 104 samples per second), previously defined as a long
5   run, are recorded. There is clear evidence of periodicity in the amplitude of events registered by a single accelerometer as a function of mill rotation angle.

A very useful representation of accelerometer response data is in terms of a contour plot of vibrational
10   event numbers as a function of SAG mill phase angle and event magnitude. This approach nominally allows vibration events to be identified with particular locations in the rotation cycle of the mill. In this manner differences can be identified in SAG mill operation both between different
15   rotation periods and with changes in mill operating conditions. The identification of the boundaries of contact of the SAG mill charge with the liner is potentially important as they can be used to deduce the volume of the charge. The position of the average or weighted average
20   phase angle of acoustic events may also be important in this regard. Charge volume (mill load) is a critical input for SAG mill control.

Figure 4 shows a vibrational event polar contour plot for an 'average' mill revolution, based on the same
25   data set as the Fig. 3 accelerometer response.

Figure 4 shows that vibrational events sensed on the outside of the shell are concentrated in regions where either the charge is expected to be in contact with the liner or cataracting grinding media in the adjacent region
30   inside the shell are expected to directly impact on the liner. The frequency of large amplitude events is maximal in what is interpreted as the 'toe' of the charge (where cataracting grinding media impact against the SAG mill charge) and in the adjacent region at higher phase angles
35   where cataracting grinding media may be directly impacting on the inner liner. The ability to identify expected regions of strong vibrational activity supports the view

that the accelerometer signal is dominated by a locally generated component. Hence it is inferred that there is strong damping of vibrational waves as they propagate around the shell. Conversely, Fig. 4 also clearly shows

5   that there is a registration of lower strength vibrational events in regions where the charge and grinding media are not expected to be in contact with -the shell liner. These lower amplitude signals are most likely due to surface vibrational waves propagating around the shell from other

10   regions. The degree of vibration signal localisation for a charged, rotating SAG mill has not yet been quantified. However, it seems likely that very high energy events registered by an accelerometer on the outside of the mill shell at a particular phase angle do reflect collisions in

15   the adjacent region of the inner liner.

Figure 5 shows a typical power spectral density plot obtained for surface vibration waves detected by an accelerometer, based on the same set of data, Spectral features are readily apparent near the DC channel (< 100

20   Hz), around 100-20,0 Hz and near 600 Hz. Finer spikes in the power spectrum can be seen at frequencies below about 400 Hz. These features are well above the background noise level and are related to the underlying process. The signal analysis technique used is the standard Welch's method for

25   average periodograms of overlapped, windowed signal sections, based on a discrete-time Fourier transform of the samples of the process using a Fast Fourier Transform (M) algorithm. In this case the frequency range is restricted to a maximum cif 1000 Hz, based on experience that most of

30   the information of interest (and signal energy) is within this range. Power spectral density plots have also been obtained up to the Nyquist frequency (half the sampling rate) and Fig. 6 shows an example based on the same data. A prominent spectral feature is apparent at a relatively high

35   frequency (around 18000 Hz) but experience has shown that this feature is insensitive to mill operating conditions. Fourier analysis is used in order to try to represent the

accelerometer response to surface vibrational waves in terms of a superposition of sinusoidal waves at characteristic frequencies. As vibrational events are discrete entitles, another fruitful approach might be

5   wavelet analysis.

Figure 7 shows a histogram of the number of vibrational events as a function of the amplitude of the accelerometer response associated with the event. This is an important way of demonstrating both the total number and

10 distribution with amplitude of vibrational events as a function of mill operating conditions. In this manner operating conditions that lead to a relatively large number of very high amplitude vibrational events can be easily identified. Such cases correspond to conditions of high

15 liner wear. Conversely, concentration of events at a relatively low amplitude indicate ineffective particle grinding within the SAG mill.

CORRELATIONS BETWEEN SURFACE VIBRATION MEASURES AND MILL OPERATING CONDITIONS

20 As mentioned in the previous section, mean and standard deviation of sampled signal was calculated for all test runs. It was postulated that the standard deviation would be a useful measure of activity in the mill at a given set of conditions. The traces show that the amplitude

25 of the signals and the number of high amplitude (energy) signals changes for different conditions. These changes are then likely to change the standard deviation thereby creating an opportunity to establish relationships between the surface vibration features encompassed in the standard

30 deviation and actual mill operating variables.

Fig 8 shows a plot of standard deviation and mill gross power for three different mill speed settings.

The mill gross power corresponds to the overall load level in the mill i.e the higher the gross power, the

35 higher the load level. Other manipulated variables, namely ball addition and pulp density, were held constant. At each speed, the relationship between standard deviation and

gross power is linear with a negative slope. An increase in the mill gross power (load level) leads to a decrease in the standard deviation of the signal. This result is consistent with experience where the mechanism at play is thought to be increased damping as a result of the higher load level in the mill. The fitted equation for each speed differs and is likely to be indicative of some other effects that are at work. Similar relationships are being developed for other surface vibration measures listed in the previous section. The relationships shown in Fig. 8 mean that for a given speed, the standard deviation measured relates directly to the gross power of the mill which itself is an indirect measure of the load level.

Figure 9 shows a plot of the standard deviation against pulp density at two different mill conditions.

As expected, the relationships for the two conditions differ but are consistent with experience. Usually, at higher densities, the thicker slurry inside the mill acts as a more effective damper thereby reducing the severity of impacts on the shell. This assertion is reflected in the measured readings, which show lower standard deviation at higher density. Similarly at lower densities, higher surface vibration standard deviation was measured.

ALTERNATIVE TECHNOLOGIES AND APPLICATIONS

Applications of the surface vibration technique extend well beyond SAG mills to other grinding mills e.g ball mills, stirred ball mills, jet mills etc. The technique is also applicable to other comminution equipment such as crushers, impactors, and hammer mills. In fact any machine that processes material and a requirement exists for a better understanding of the mechanisms occurring inside both from a processing and condition monitoring viewpoint are potential applications of this technique. Machines, the operation of which would benefit with the application of [his technique, include but are not limited to:

- AG/SAG/ball/rod/vibratory mills
- Gyratory/cone/jaw/rolls crushers
- Vertical shaft impactors
- Hammer mills
- Vertical spindle mills
- Hydrocyclones/dense media cyclones
- Spirals
- Vibrating/DSM/banana screens
- Vibrating plate separation devices
- Flotation cells
- High pressure grinding rolls/ roller presses
- Any equipment requiring process or condition monitoring

Alternative technologies that may compete with this surface vibration technique are thought to be acoustic emission sensors, Le microphones, mounted on the mill and configured similarly to this technique. This set-up would allow acoustic emission features to be correlated against events occurring in the mill during each revolution. The hardware required to build this type of system, aside from the sensors, is likely to be very similar to the surface vibration system described above. Another possibility is to enclose a mill with a mounting frame so that the microphones are positioned around the entire circumference of the mill but are mounted off the mill. It is somewhat doubtful whether this configuration is practicable.

The arrangements of experimental apparatus and signal analysis techniques as applied to monitoring a SAG mill as described in this document have been advanced merely by way of explanation. Many modifications may be made thereto both for further monitoring of SAG mills and other material processing machines without departing from the spirit and scope of the invention which includes every novel feature and combination of novel features herein disclosed.

THE CLAIMS DEFINING THE INVENTION ARE AS FOLLOWS:

1.   A system for monitoring acoustic emissions from a machine which in operation has moving particulate matter therein, the system including at least one sensor located on the machine at a location away from the central axis of the machine, the sensors being for sensing acoustic waves and including a transmitter for transmitting signals representing the sensed acoustic waves to a receiver at a location remote from the sensor(s), a data processor connected to the receiver for receiving signals from the receiver which signals represent the acoustic waves and processing the signals to produce output signals for display on a display means, wherein the output signals for display represent one or more parameters indicative of acoustic waves emitted from the machine over a predetermined period of time.

2.   A method of analysing operational parameters of a machine having a moving particulate material therein, the method including the steps of recording data representing a number of vibrational events occurring within the machine over a predetermined period of time, the amplitude of the vibrational events occurring over the predetermined period of time and positional data relating to the position of the vibrational events occurring within the machine, displaying a graphical representation of the recorded data, the graphical representation including parameters relating to the number of vibrational events, the amplitude of vibrational events and the position of vibrational events occurring within the machine during the machines operation.

3.   A method of controlling operational parameters of a machine having a moveable substance therein, the method including the steps of recording data representing a number of vibrational events occurring within a machine over a predetermined period of time, amplitude of the vibrational events occurring over the predetermined period of time and position data relating to

the position of the vibrational events over the predetermined period of time, determining zones within the machine which are subject to predetermined levels of wear and altering the machine operational characteristics to

5 reduce the levels of wear for the zones.

Dated this 9th day of July, 1999

COMMONWEALTH SCIENTIFIC AND INDUSTRIAL RESEARCH ORGANISATION

By their Patent Attorneys

10 GRIFFITH HACK

Fellows Institute of Patent and

Trade Mark Attorneys of Australia
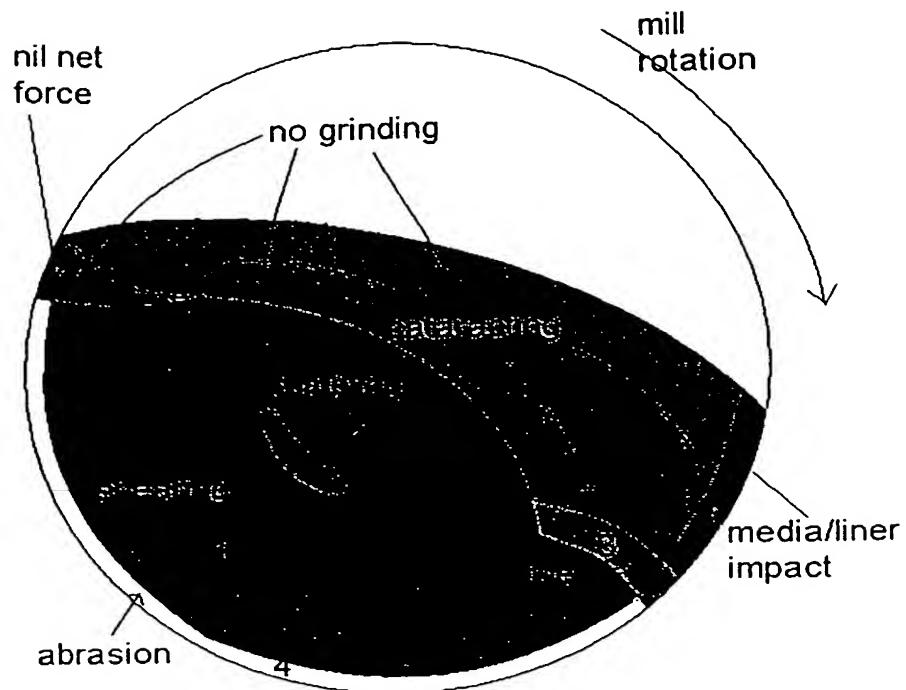
FIGURE 1
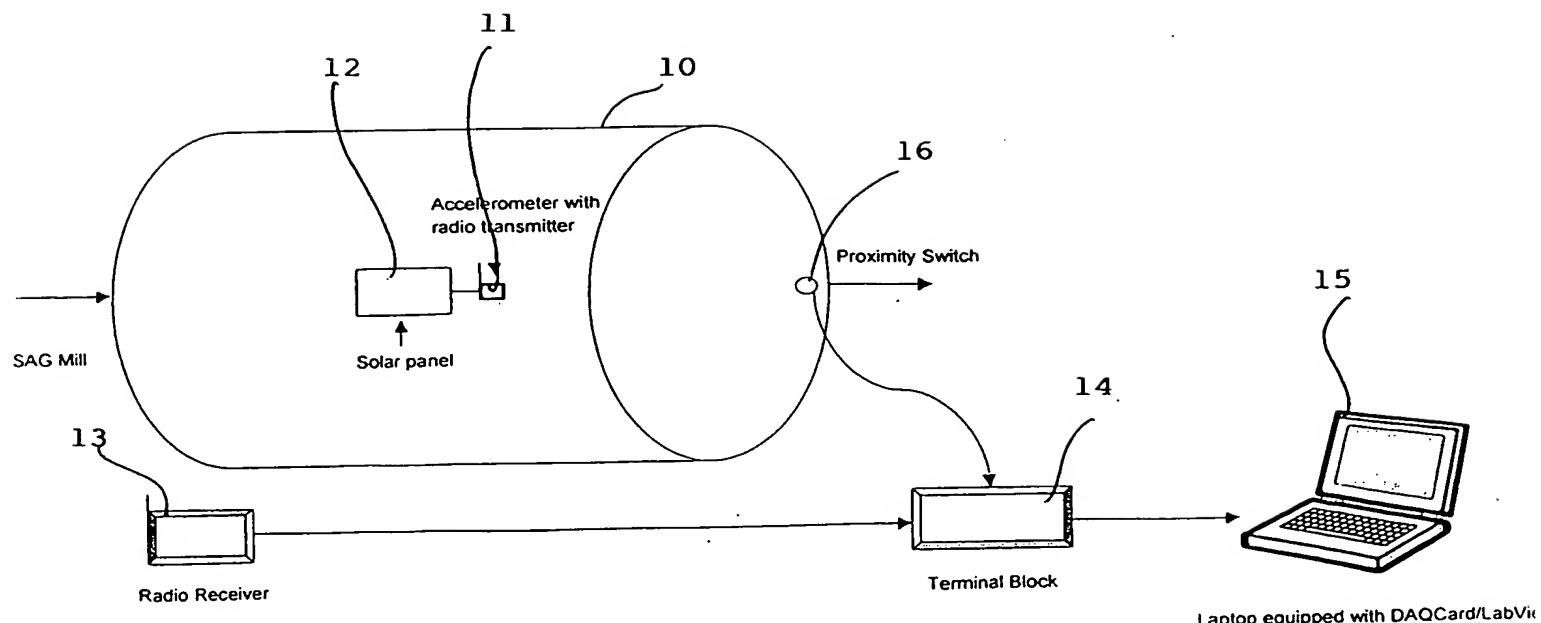
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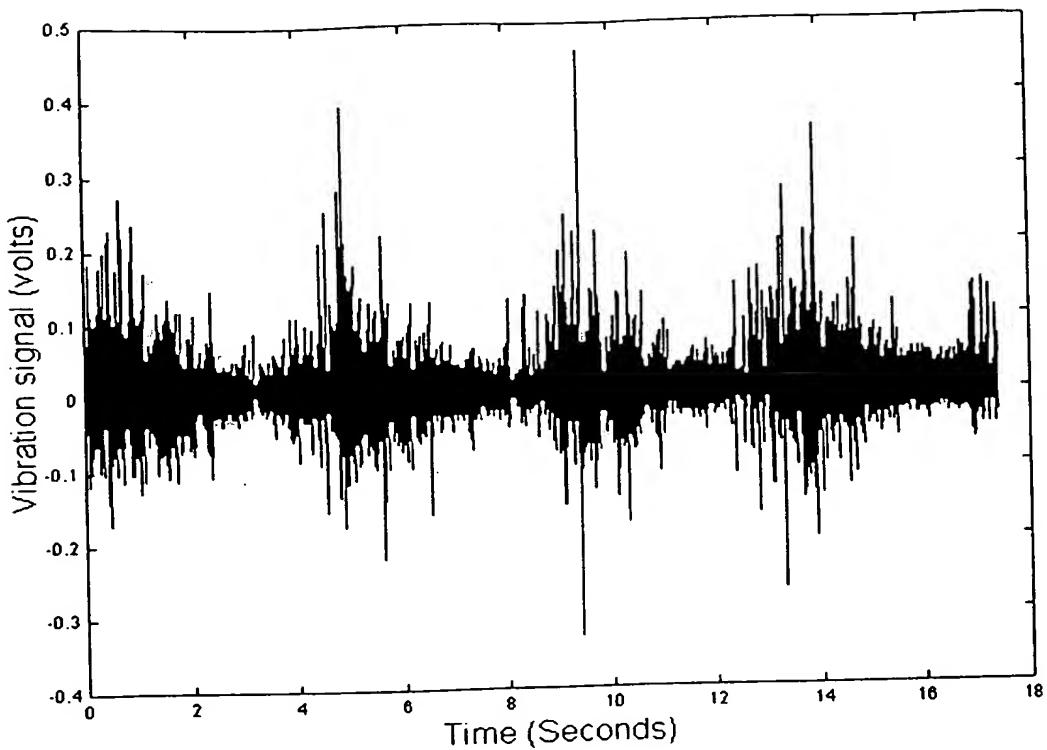
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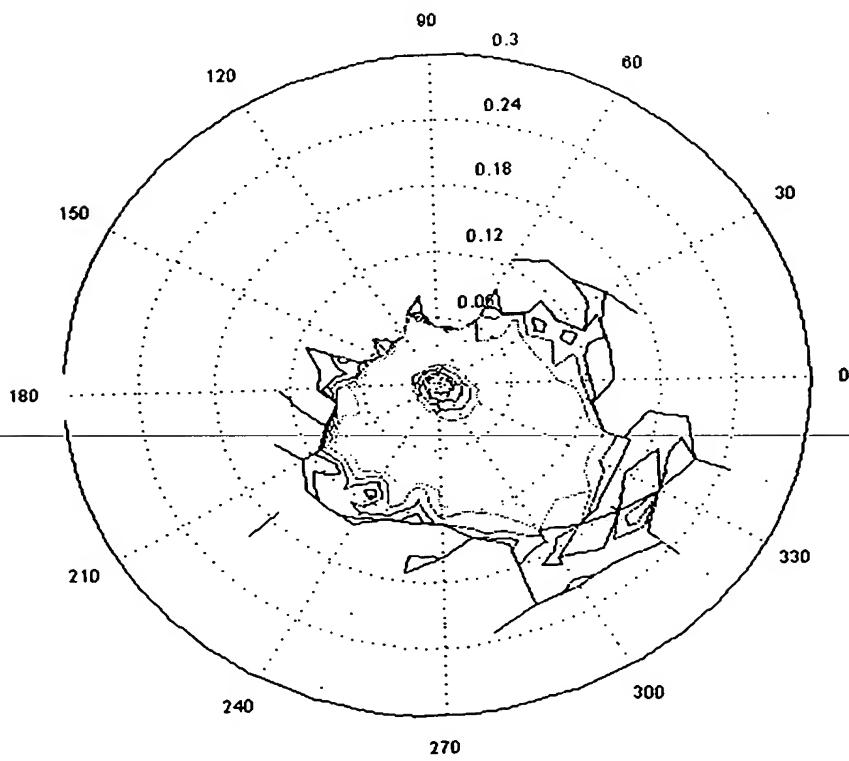
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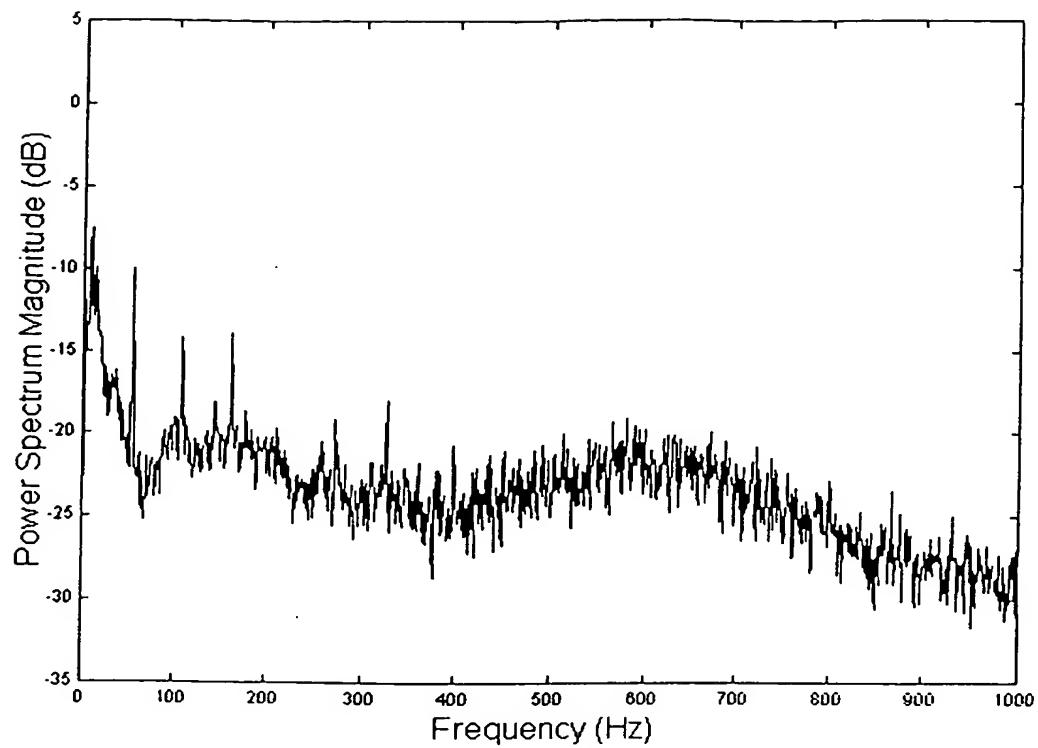
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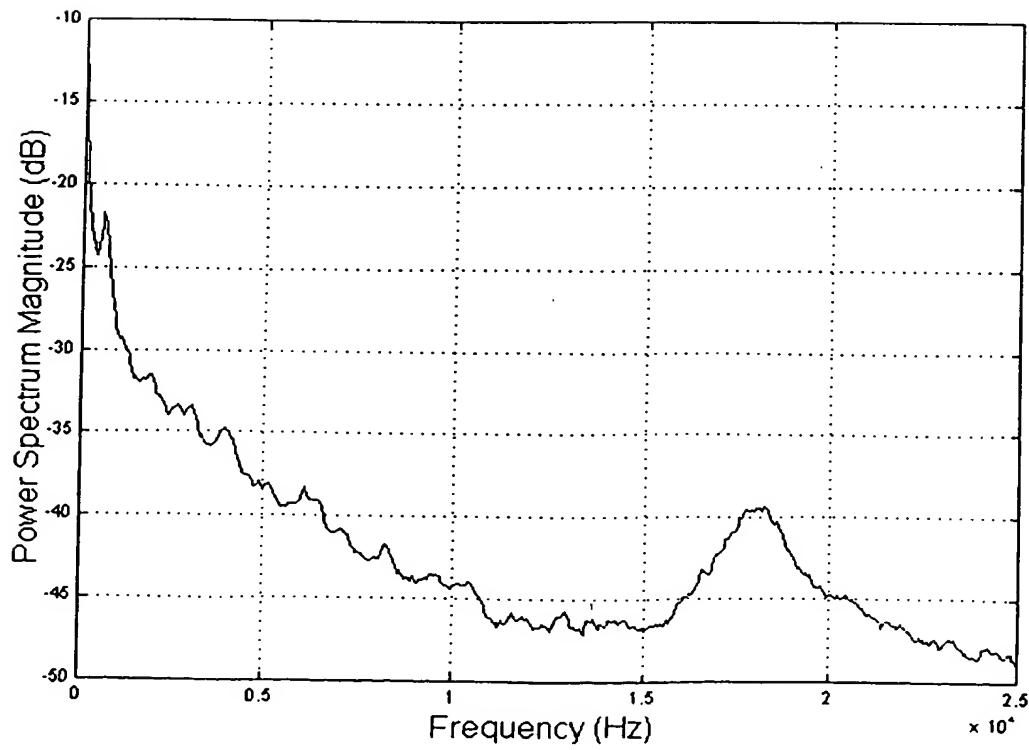
FIGURE 6

FIGURE 7

FIGURE 8

AE SD vs Density
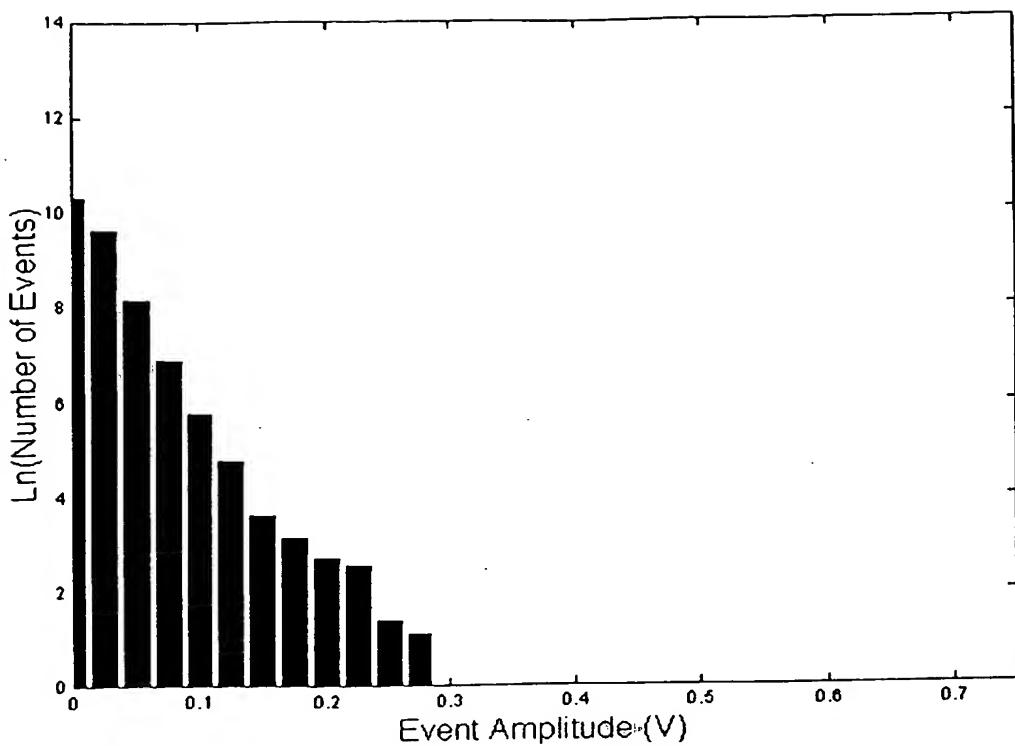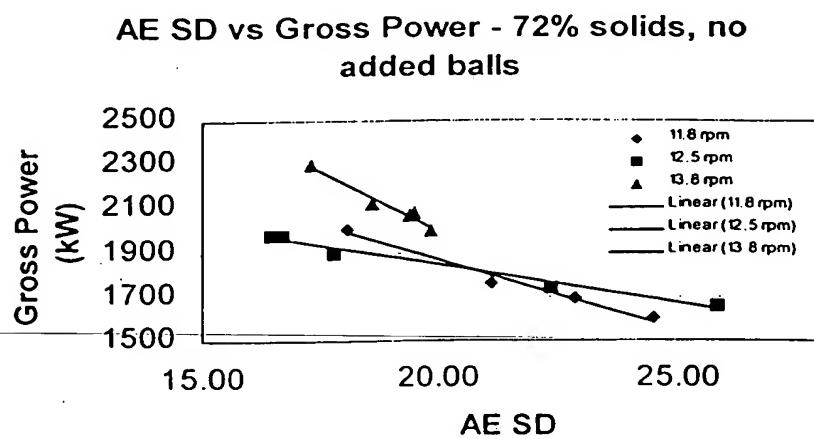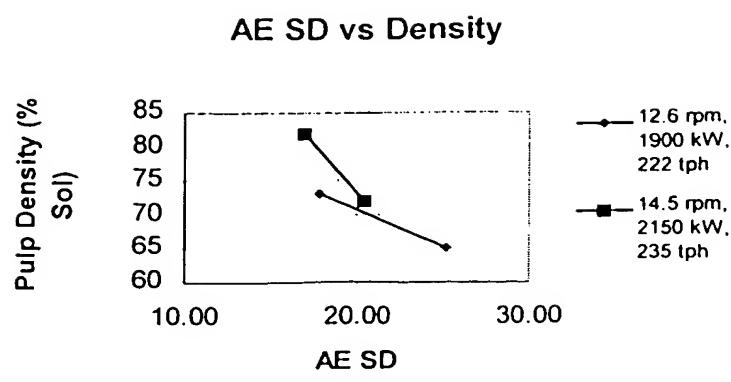
FIGURE 9

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